

Synthesis, Spectroscopic characterization and invitro bacterial evaluation of Ni(II) complexes of new tridentate aroylhydrazone ligands

Pramod Kumar Singh, Kamalika Banerjee, Sangeeta Singla

Abstract—Nickel(II) complexes of four new aroylhydrazones, N-(2-hydroxy-1-naphthaldehyde)-N'-(4-nitrobenzoyl)hydrazone (H_2L^1), N-(2-hydroxy-4-methoxybenzaldehyde)-N'-(2-furoyl) hydrazone (H_2L^2), N-(2-hydroxyacetophenone)-N'-(2-theonyl) hydrazone (H_2L^3) and N-(2-hydroxy-5-methylacetophenone)-N'-(3-toloyl) hydrazone (H_2L^4) have been synthesized. The structure of these complexes has been investigated using elemental analysis, magnetic susceptibility, molar conductance, thermogravimetric analysis and spectral (IR, electronic, NMR) measurements. IR spectra indicates that the ligand behave as dibasic tridentate ligand and coordinate to Ni(II) ion through ketonic oxygen, azomethine nitrogen and phenolic oxygen atom (except in H_2L^1 by naphtholic oxygen atom) by double deprotonation. TG curve show decomposition of the complexes with NiO being the final decomposition product confirmed by X-ray data. The magnetic and spectral data suggest the octahedral geometry for all the Ni (II) complexes. Antibacterial activity of the ligand and their Ni(II) complexes were studied against both Gram-positive (*staphylococcus aureus*) and Gram-negative

(*Escherichia coli*, *Klebssiella pneumoniae*) bacteria using minimum inhibitory concentrations (MICs) method.

Keywords— Ni(II) complexes, enolic proton, phenolic proton, Azomethine. Nitrobenzoyl hydrazones, furoyl hydrazones, theonyl hydrazones.

I. INTRODUCTION

The N-substituted hydrazones of aldehyde and ketones play an important role in biological and pharmaceutical activities [1-5] and as well as considerable chelating ability with transition metals [6-10]. In continuation of earlier work [6,7] on metal complexes, this paper presents the synthesis and characterization of four new ligands:

N-(2-hydroxy-1-naphthaldehyde)-N'-(4-nitrobenzoyl) hydrazone (H_2L^1),
N-(2-hydroxy-4-methoxybenzaldehyde)-N'-(2-furoyl) hydrazone (H_2L^2),
N-(2-hydroxyacetophenone)-N'-(2-theonyl) hydrazone (H_2L^3) and
N-(2-hydroxy-5-methylacetophenone)-N'-(3-toloyl) hydrazone (H_2L^4) as shown in Figure 1.

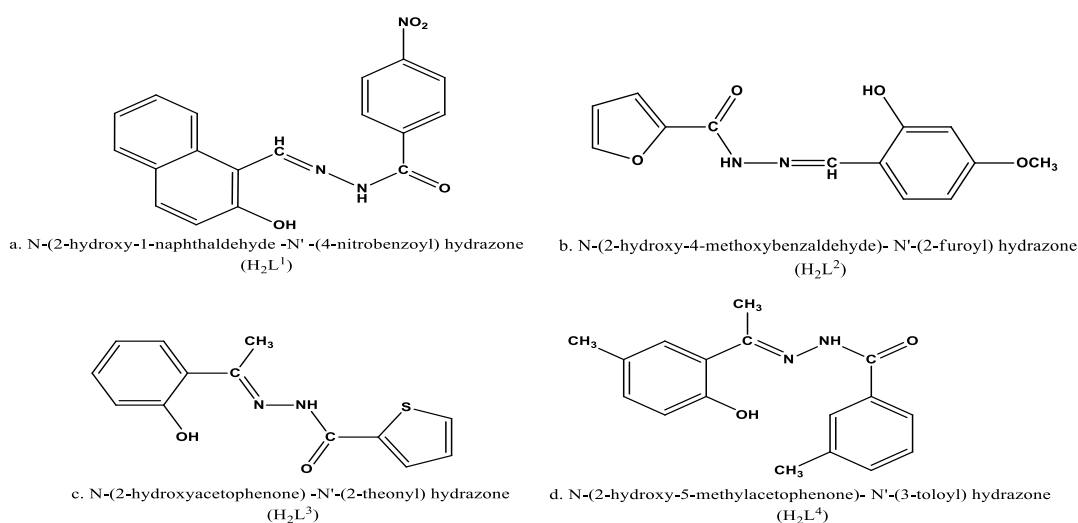


Fig.1: Structure of the Ligands.

II. EXPERIMENTS

All the chemicals and metal salts used in the synthesis were of reagent grade and used without purification. The solvents were dried before use by conventional method.

2.1. Synthesis of the ligand

All the four ligands were obtained by condensation of ethanolic solution of acid hydrazides with ethanolic solution of hydroxyl aromatic aldehydes and ketones. The structures of the aforementioned ligands were identified by elemental analysis, IR and ^1H NMR. The purity of the ligands was checked by TLC. Ligands 2-furoyl hydrazine [11] and 2-hydroxy -5- methylacetophenone [12] were prepared by known method.

The ligand H_2L^1 was obtained by condensation reaction of 2-hydroxy-1-naphthaldehyde with 4-nitrobenzoylhydrazide in ethanol at 1:1 molar ratio by heated for 4 hrs. under reflux. The precipitate produced was separated by filtration, washed twice with hot ethanol and dried in vacuum. H_2L^2 , H_2L^3 and H_2L^4 were also obtained by the method similar to that of H_2L^1 .

2.2. Synthesis of complexes

Complex $[\text{NiL}^1].2\text{H}_2\text{O}$ was prepared by boiling under reflux, equimolar amounts of ligand H_2L^1 in absolute alcohol (10 cm^3) and nickel(II) acetate tetrahydrate in absolute alcohol (10 cm^3) with stirring. After 3 hrs. the brown colored complex was filtered off, washed with ethanol followed by ether and then dried in vacuum. Complex $[\text{NiL}^2].2\text{H}_2\text{O}$, $[\text{NiL}^3].2\text{H}_2\text{O}$ and $[\text{NiL}^4].2\text{H}_2\text{O}$ were prepared by following similar procedure. All the complexes behave as 1:1 electrolyte in DMF solutions.

III. ELEMENTAL ANALYSIS AND PHYSICAL MEASUREMENTS

C, H and N were determined micro analytically and metal contents were estimated using Perkin-Elmer 2380 atomic absorption spectrophotometer. IR spectra were recorded on Perkin -Elmer FT-IR spectrophotometer as KBr discs in the $4000\text{-}200\text{cm}^{-1}$ region. Electronic spectra were recorded in DMF on Beckman DU-2 spectrophotometer. ^1H NMR spectra were recorded on Varian FT-80A NMR spectrophotometer using $\text{DMSO-}d_6$ as solvent and TMS as internal standard. Magnetic measurements were carried out at room temperature using Gouy's method employing $\text{Hg}[\text{Co}(\text{SCN})_4]$ for calibration purpose and were corrected for diamagnetism by using Pascal's constants. Molar conductance was measured in DMF (10^{-3}M) with digital conductivity model 304 X-band. Thermal behavior was monitored on 8150 thermo analyzer at the heating rate of $10^\circ\text{C}/\text{min}$. The X-ray diffraction patterns on each of the TG residues were taken on a Philips diffractometer.

IV. RESULTS AND DISCUSSIONS

All the complexes were air-stable, non hygroscopic, decomposes at higher temperature, insoluble in common organic solvents, but soluble in strong polar solvents, such as DMF and DMSO. The stoichiometries of the complexes have been deduced from elemental analysis result (Table -1) which indicate that the ligand co-ordinate to the metal ion in 1:1 molar ratio. The melting points of the complexes are higher than that of the ligand revealing that the complexes are much more stable than the ligands. The molecular weights of the complexes could not be obtained by cryoscopy due to insolubility of the complexes in benzene/nitrobenzene. The molar conductance value of the Ni(II) complexes lies in the range of 22.90 to 27.69 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ (at 15°C) indicating non electrolytic nature of the complexes [13].

Table.1: Elemental Analysis of Ni(II) complexes

Ligands	Decomposition Temperature ($^\circ\text{C}$)	Color	Yield (%)	Found (Calculated) %				Molar conductance ^a $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$
				C	H	N	M	
$[\text{H}_2\text{L}^1]$ ($\text{C}_{18}\text{H}_{13}\text{O}_4\text{N}_3$)	206-208	White	79.20	63.80 (64.48)	3.20 (3.88)	12.10 (12.54)	—	—
$[\text{H}_2\text{L}^2]$ ($\text{C}_{13}\text{H}_{12}\text{O}_4\text{N}_2$)	180-186	White	75.00	59.30 (60.00)	4.00 (4.62)	10.12 (10.77)	-	-

[H ₂ L ³] (C ₁₃ H ₁₂ N ₂ O ₂ S)	182-185	White	82.10	58.90 (60.00)	4.20 (4.62)	10.50 (10.77)	-	-
[H ₂ L ⁴] (C ₁₇ H ₁₈ N ₂ O ₂)	190-194	White	89.60	71.97 (72.05)	5.80 (6.10)	9.47 (9.76)	-	-
[NiL ¹].2H ₂ O	248-252	Dark brown	73.00	50.21 (50.50)	3.32 (3.50)	9.69 (9.82)	17.49 (17.72)	22.90
[NiL ²].2H ₂ O	235-240	Brownish red	71.25	44.10 (44.23)	3.79 (3.96)	7.69 (7.93)	16.39 (16.64)	23.64
[NiL ³].2H ₂ O	245-250	Light brown	74.12	44.10 (44.23)	3.75 (3.96)	7.67 (7.93)	16.41 (16.64)	27.69
[NiL ⁴].2H ₂ O	250-255	Dull red	73.25	54.19 (54.44)	5.10 (5.33)	7.21 (7.47)	15.37 (15.66)	26.25

4.1. IR Spectra

The IR spectra of the ligand and complexes were recorded as KBr discs in the 4000-200cm⁻¹ region. The IR spectra of the ligand shows the characteristics absorption band at 3141-3279, 1640-1672, 1540-1570, 1490-1525 and 955-970 cm⁻¹ are attributed to ν (N-H), ν (C=O), ν (C=N), δ (N-H) and ν (N-N), respectively.

The IR spectra of the complexes reveal significant changes compared to those of the ligands. The absorption bands at 3490-3540 cm⁻¹ for ν (O-H) in the free ligands disappeared on complexation, indicating coordinated through a deprotonated oxygen. The bands due to ν (N-H), ν (N-N) and δ (N-NH) are absent in these complexes suggesting the loss of carbonyl group due to enolization. This is further supported by the appearance of two new bands observed in the region 1590-1620 and 1290-1330 cm⁻¹ attributed to ν (=C=N-N=C=) and ν (NCO⁻) vibrations respectively [14]. The spectra of the complexes show that furoyl ring oxygen and theonyl ring sulphur does not participate in bonding to a Ni(II) ion [15]. The band of ν (C=N) of all the ligands undergoes a bathochromic shift by ca 40-80 cm⁻¹ where as ν (N-N) band exhibits a hypsochromic shift of ca 35-55 cm⁻¹, which indicate that the Ni(II) ion form neutral coordination compound with the ligands in the enol form through the azomethine nitrogen and amide oxygen negative ion [16].

A shift of ν (C=N) band to a lower frequency is due to the conjugation of *p* orbital on the double bond with *d* orbital on the Ni(II) ion with reduction of force constant. A shift of ν (N-N) band to a higher frequency is attributed to the

electron attracting inductive effect when forming the conjugated system [7]. The characteristic band due to naphthyl ring and phenyl ring of the ligands and their chelates is not changed. In the far IR region two new bands ca 460-480 and ca 340-370 cm⁻¹ in all complexes can be assigned to ν (Ni-O) and ν (Ni-N) bands respectively [17]. The new broad band ca 3370-3400 cm⁻¹ in all the complexes assigned to the O-H stretching vibration which indicates that water molecules is in the complexes.

4.2. ¹H NMR Spectra

The ¹H NMR Spectra of the ligands were recorded in DMSO (*d*₆) using TMS as internal standard. There are two sharp singlets at very downfield region of the spectrum i.e. at δ 10.90 and δ 10.10 ppm in all ligands are assigned to OH and NH protons respectively. The down field shift of these protons suggest the possibility of considerable extent of hydrogen bonding involved, which decreases the electron density around the proton and moves the proton absorption to lower field.

The ¹H NMR of the ligand H₂L¹ shows peak of naphthalene ring proton at δ 6.20-8.60 ppm (multiplets), NCH proton at δ 8.55 ppm (singlet), nitrobenzoyl proton at δ 8.15 ppm (doublet) and δ 8.35 ppm (doublet). The lower value of nitrobenzoyl proton at δ 8.15 ppm (doublet) compared to δ 8.35 is due to presence of electron withdrawing nitro group at its ortho position.

The ¹H NMR of the ligand H₂L² shows peak of NCH proton at δ 8.55 ppm (singlet), methoxy proton at δ 3.77 ppm

(singlet), three peaks of aromatic ring protons in the range of δ 6.53-7.47 ppm and three peaks in the range of δ 6.67-7.88 ppm due to slight different environment of three furyl protons



The ^1H NMR of the ligand H_2L^3 shows peak at δ 2.35 ppm (singlet) for $\text{H}_3\text{C}-\overset{\text{I}}{\text{C}}=\text{N}-$ methyl protons, a complex pattern of peaks in the range δ 7.80 ppm for aromatic protons and three peaks in the range of δ 6.67-7.75 ppm for the three theonyl protons in different environments.

The ^1H NMR of the ligand H_2L^4 also shows peak at δ 2.39 ppm (singlet) for $\text{H}_3\text{C}-\overset{\text{I}}{\text{C}}=\text{N}-$ methyl protons, at δ 2.20 ppm (singlet) for aromatic methyl proton and a complex pattern was observed in the range δ 6.70-7.95 ppm for acetophenone ring protons and totyl protons.

The ^1H NMR spectra of the complexes cannot be obtained due to interference in their paramagnetic properties.

4.3. Electronic Spectra and Magnetic studies

The Electronic spectra (Table-II) of all complexes were recorded in DMF at room temperature. The electronic spectra of all the four ligands. H_2L^1 , H_2L^2 , H_2L^3 and H_2L^4 exhibit three peaks in UV region. The peak at 3145 cm^{-1} is attributed to $\pi - \pi^*$ transition of the benzenoid moiety of the ligand. The peak around 29000 cm^{-1} can be assigned to intra ligands $\pi - \pi^*$ transition. The other peak observed in the region of 27770 cm^{-1} is attributed to $n-\pi^*$ electronic transition. The electronic spectra of Ni(II) complexes displayed three bands in the range 8890-10350, 14570-15000 and $21540-25050\text{ cm}^{-1}$ distributable to $^3\text{A}_{2g} \rightarrow ^3\text{T}_{2g}(\text{F})$ (ν_1), $^3\text{A}_{2g} \rightarrow ^3\text{T}_{1g}(\text{F})$ (ν_2), $^3\text{A}_{2g} \rightarrow ^3\text{T}_{1g}(\text{P})$ (ν_3) transitions respectively., suggesting octahedral geometry around Ni(II) ion (6,13). The value of transitions ratio ν_2/ν_1 and β lies in the range of 1.65-1.70 and 0 respectively indicates octahedral geometry of the complex. The β value obtained are less than unity indicates covalent character of the metal ligand bonds. Ni(II) complexes are paramagnetic and magnetic moment values lies in the range 2.80-3.50 B.M. indicates the expected spin free octahedral complex[17,18].

Table.2: Electronic Spectral Data (cm^{-1}) and magnetic moments (B.M.) of metal complexes.

Complexes	ν_1	ν_2	ν_3	ν_2/ν_1	β	$\mu_{\text{eff.}}(\text{B.M.})$ at room temperature
$[\text{NiL}^1].2\text{H}_2\text{O}$	10200	14570	21540	1.429	0.89	2.98
$[\text{NiL}^2].2\text{H}_2\text{O}$	10350	15000	22340	1.450	0.92	3.10
$[\text{NiL}^3].2\text{H}_2\text{O}$	8890	14870	25050	1.673	0.90	2.80
$[\text{NiL}^4].2\text{H}_2\text{O}$	8900	14900	25000	1.64	0.91	3.20

4.4. Thermogravimetric analysis

Thermogravimetric experiments of the ligands and the Ni(II) complexes were carried out in the temperature range $50-850^\circ\text{C}$ with a heating rate of $10^\circ\text{C}/\text{min}$. The first peak appeared in the range of $235-255^\circ\text{C}$ which corresponds to melting point of ligand because no weight loss were observed in TG curve, while the second peak were observed in the range of $340-375^\circ\text{C}$ where the weight loss on the corresponding curve indicates decomposition of ligands which continues up to 490°C .

The thermal decomposition of Ni(II) complexes occurs in three distinct stages. The first step in the decomposition sequence at $135-160^\circ\text{C}$ corresponds to loss of physically bound water molecule from the crystal lattice, leading to the formation of anhydrous chelate, which is also supported by

IR spectra of the complex. The second step of decomposition lies in the range of $235-245^\circ\text{C}$ corresponds to weight loss of Nitrogen. The third step of decomposition starts from 320 to 490°C as indicated by the horizontal plateau on the TG curve of all Ni(II) complexes. This decomposed fragments could not be approximated owing to continuous loss, indicates the decomposition of organic part of the chelate. The final weight loss of the residue in the temperature range $600-800^\circ\text{C}$, as shown by horizontal plateau on the TG curve corresponding NiO residue [19]. X-ray diffraction data obtained on each of the TG residues were verified for the formation of NiO and presented in the Table 3. The observed d -values are in agreement with the reported data for NiO.

Table.3: d -spacing (A ; $\lambda=5405\text{\AA}$) for NiO obtained from TG residues of Ni(II) complexes.

Reported		Observed	
d -spacing	Relative intensity I/I_0	d -spacing	Relative intensity I/I_0

2.410	91	3.2009	20
2.088	100	2.825	31
1.476	57	2.764	16
1.259	16	2.514	17
1.206	13	2.438	86
1.0441	8	2.238	74
0.9582	7	2.148	67
0.9337	21	2.084	55
0.8527	17	1.570	24
0.8040	7	1.480	51
		1.236	14
		1.120	11
		1.086	21
		0.644	31
		1.430	8
		0.9827	12
		0.8624	20
		0.821	13
		0.7616	7
		0.6420	18
		0.5317	6
		0.4321	8

Summerising our results, we propose a plausible structure of Ni(II) complexes in Figure 2 (a,b,c,d).

4.5. Antibacterial Activity

The ligand and their nickel complexes were screened for their antibacterial activity against both Gram-positive (staphylococcus aureus) and Gram-negative (Escherichia coli, Klebsiella pneumoniae) bacteria and the results are presented in Table 4..

Table.4: Antimicrobial activity of Ligands and its Ni(II) complexes.

Compound	Bacteria/Inhibition Zone(mm)		
	S. Aureus	E. Coli	K. pneumoniae
H ₂ L ¹	6	7	6
H ₂ L ²	6	7	7
H ₂ L ³	7	7	8
H ₂ L ⁴	6	6	7
[NiL ¹].2H ₂ O	12	16	17
[NiL ²].2H ₂ O	12	18	18
[NiL ³].2H ₂ O	13	18	17
[NiL ⁴].2H ₂ O	14	19	18

The ligands have a weak action on all the microorganisms but the activity of the ligands become more pronounced when coordinated to the Ni(II) ions and action of the Ni(II) complexes on the Gram-negative bacteria is better than Gram-positive bacteria. all the Ni(II) complexes have same donating atoms (O, N, O), with same oxidation state of Ni(II) ion and the same octahedral geometry, hence the higher activity of the complexes compared to the ligand can be attributed to the nature of donor atoms of the ligands which are involved in the chelation. Furthermore chelation reduces the polarity of the Ni(II) ion because of the partial sharing of its positive charge with the donor groups and possibly the π electron delocalization within the whole chelate ring system that is formed during coordination [20]. These factors increases the lipophilic nature of the central metal atom and

hence increasing the hydrophobic character and liposolubility of the molecule favoring its permeation through the lipid bilayer of the bacterial membrane. This enhance the rate of uptake/ entrance and thus the antibacterial activity of the testing compound.

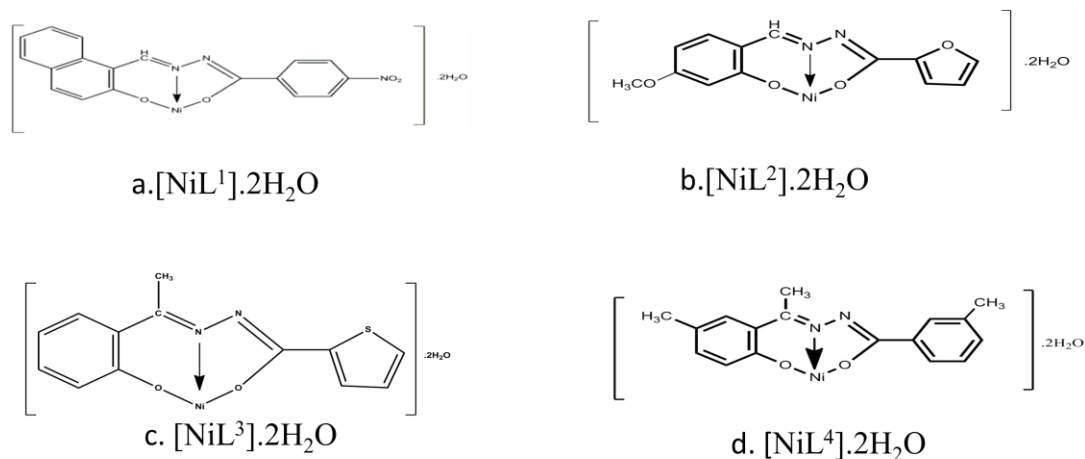


Fig.2: Proposed structure of the Ni(II) complexes.

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